Underwater Object Identification in Laser Line Scan Imagery

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Contract #: N0001499CO188

LONG-TERM GOAL

Our long term goal is to provide the Navy with a robust automated target cueing and identification capability for use with high resolution underwater imaging sensors such as Raytheon's laser line scan system. These electro-optical sensors operate at standoff ranges to survey large areas of the underwater environment in search of naval targets of interest and are currently being incorporated into sonar towbodies to create high probability of detection and low false alarm rate mine countermeasure (MCM) systems.

OBJECTIVES

The objectives of this year's effort are two-fold. First, we have set out to determine and demonstrate the ability of a multi-spectral laser line scan sensor to optically excite and exploit fluorescence phenomena and thereby facilitate the identification of underwater mines and mine-like objects. Of particular interest are targets that have been in a shallow water littoral environment for extended periods of time and have thus been subject to degrading processes such as corrosion and bio-fouling.

Our second objective is to adapt and assess the ability of an existing automatic target cueing and recognition approach to separate and classify underwater targets of interest from the natural background in either single (i.e. reflectance) or multi-channel (i.e. flourescence) laser line scan imagery. This objective ties this year's effort into our long term MCM goals independent of any immediate conclusions that may be drawn about the utility of exploiting fluorescence imagery.

APPROACH

Survey Phase:

The first phase of our project was a survey of a target-rich shallow water environment approximately 10 miles southwest of Key West, FL. The survey was conducted to acquire multi-channel fluorescence imagery of submerged mine-like objects of interest, presumed to be defused WWII mines laid to protect the local shipping lanes. The survey was performed on the *Sea Diver*, supplied by the Harbor Branch Oceanographic Institute (HBOI). The Fluorescence Imaging Laser Line Scanner (FILLS) used to acquire the imagery was installed in a Coastal Systems Station (CSS) developed and operated active depressor towbody that was towed behind the *Sea Diver.* The towbody also housed forward, and down-looking sonars that provided for wide area target-like object locating and navigational control. In addition, *in situ* water samples and measurements to characterize the water column were made by Dr Dave Phinney and his group from Bigelow labs.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Underwater Object Identification in Laser Line Scan Imagery**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Raytheon Systems Company,Advanced Optical and Recce Systems Center,Tewksbury,MA,93093-0218**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

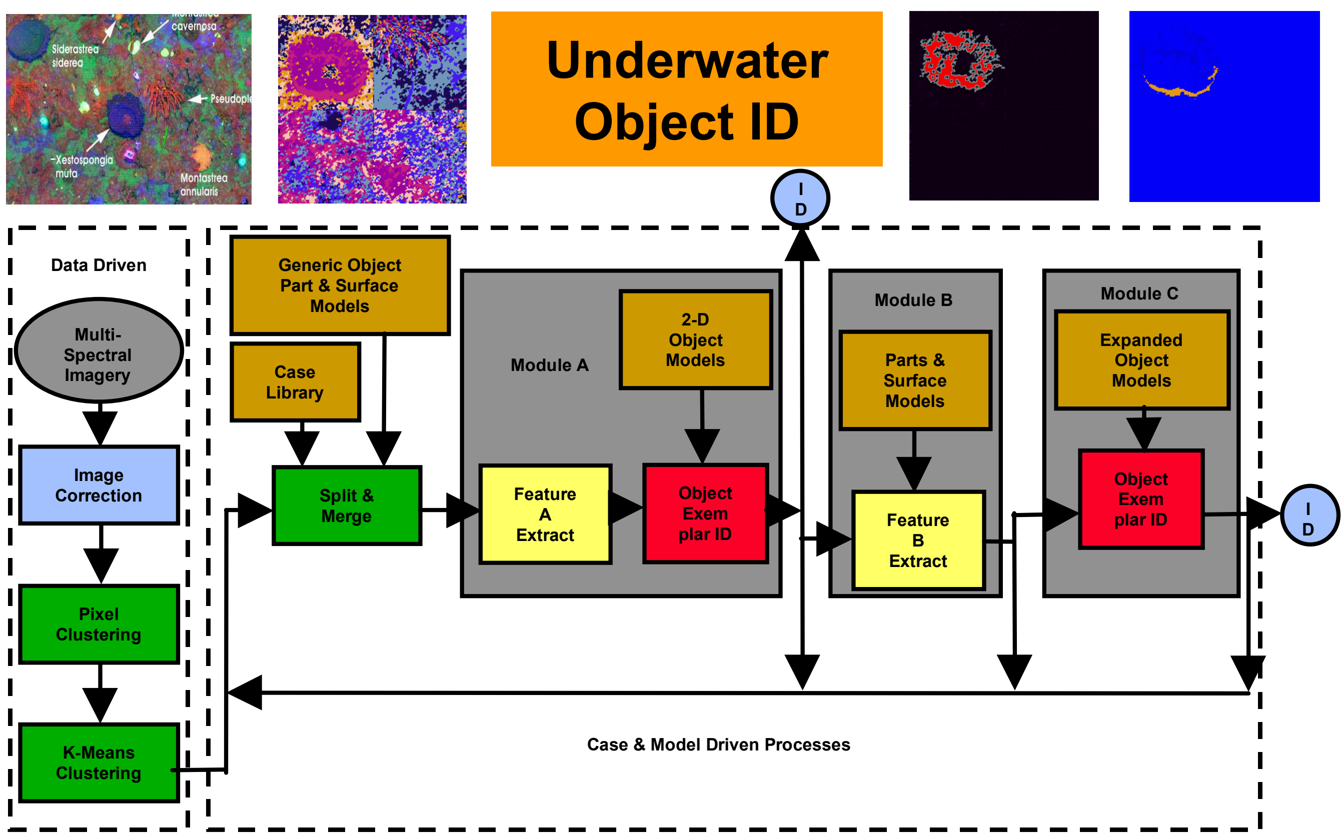
15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The survey consisted of multiple tracks over a highly bio-fouled mine and adjacent anchor that had earlier been located, marked, and video documented by a dive team. The team also emplaced a calibration panel, prepared by Dr. Charles Mazel of PSI, containing four two-foot squares of green, yellow, and red fluorescing materials. The panel was situated such that it would be imaged along with the mine to assess the water column impact on FILLS-induced fluorescence. Additional survey tracks were made over an area known to contain multiple minefield lines. The objective of these passes was to obtain multiple target samples to better define this class of objects in support of algorithm development.

Data Analysis Phase:



1. Multi-Stage Object Identification Processing Flow Diagram

The second phase of our project commenced in late August and is scheduled to continue through December 1999. In this phase, we are adapting Raytheon proprietary target cueing and object identification algorithms to detect and classify mine-like objects in single and multi-channel laser line scan imagery. After the adaptation is completed, we will process imagery collected at Key West and at other locations to gain an improved understanding of the issues associated with detecting and identifying underwater objects over a range of attenuation and scattering conditions.

The target cueing approach for this project is an adaptation and extension of the image processing suite developed to detect and extract features from mine-like objects for the Army's Airborne Standoff Minefield Detection (ASTAMIDS) program. The approach automatically detects objects with shapes that can be approximated by an ellipse within a range of target-like sizes and eccentricities. The processing stages include: mean downsampling to lessen downstream throughput and improve the signal-to-noise ratio; Sobel filtering with adaptive local binarization to yield object outlines; geometric feature extraction to determine object size, shape, and fit to an ellipse; and a simple decision rule that operates on the feature set and incorporates rudimentary knowledge, such as the size and shape of known mines. Typically, this processing is done in real-time and the results are presented to the user as an icon or pointer overlay on an image display. The overlays draw the viewer's attention to mine-like objects and allow more time for a target or no target decision before the next scene is presented.

In our long term goal, the cuer will handoff regions of interest to a more computationally intensive object identifier to form a fully automated target ID processing chain. The object identifier will definitively declare a target-like object (from the cuer) to be either a target or non-target and will, ideally, eliminate the need for a subjective human decision. Our approach to complex environment object identification is a vision system, whose processing framework is depicted in Figure 1, that incorporates multiple classification strategies. Each strategy has strengths as well as weaknesses but they are designed to compliment each other well when used in concert within the framework.

To this point, a hybrid generic- and case-based modeling approach incorporating elements of the *Exemplar, Generic*, and *Abstraction* strategies (see below) has been implemented with some success for a limited set of naturally-occurring underwater objects such as sponges and corals. In this project, we will further develop those strategies that are deemed critical to support mine detection based on an analysis of data collected from Key West and other deployments. A brief discussion of the classifier strategies are given in the following paragraphs.

Exemplar-Based Strategy (viewer-centered): Classification is achieved by determining the object exemplar most similar to the new item. The system begins by using superficial (raw) features to make an initial hypothesis and verifies the hypothesis by finding an exemplar from that category that matches the new findings well

Generic Recognition Strategy (object-centered): To complement the weaknesses of the exemplar-based recognition strategy, object recognition must rely on coarse, qualitative models representing classes of objects. The generalization process with 'simple' operations and inferential reasoning can achieve the 'near' viewpoint-invariant 3D features from the readily perceivable (superficial) features.

Learning-Based Strategy: In the human visualization system, it is hypothesized that descriptions of objects built from features are learned from examples. Experts in the field believe that machine learning is driven by the notion that algorithms and systems can improve their performance with time. To evaluate the effectiveness of the generalized/hypothesized features for discriminating objects and improving the vision system's efficiency, the following learning elements are essential: compiling compiling; updating feature significance levels; identifying redundant features; evaluating the affects of near/far misses and too few/many activated objects; updating uncertainty and (object) variety for fuzzy representation of features; and ranking features by discrimination power and by their ease/difficulty of computation.

Evidence-Based Strategy: In this strategy, object recognition is regarded as the task of obtaining a subset of image parts whose properties and relations satisfy a set of constraints for rapid object invocation. Rather than using static, pre-specified models, a vision system would be able to derive specific model information dynamically from sensor input by using a "teach-by-example" technique, such as a learning-based strategy. In this framework, recognition is based on the strength of collective evidence. The hypothesis is that discrimination power is induced by a collective set of diverse and abundant (individually) weak features.

Abstraction-Based Strategy: Ideally, the multiple techniques discussed earlier must have stages that are closely integrated. The results of each stage would provide feedback to refine the techniques used at a previous stage. In the abstraction-based paradigm, a hypothesis-verification strategy is used to extract abstractions from the data (*features* based on explicit assumptions made on data). To determine whether the assumptions are applicable, the abstractions are instantiated and then tested for verification. The successful abstractions are then incorporated into the data set to modify the model-base with improved context information. To support the system's concept formation and adaptation capability, in relation to the uncertainties of each of the 3D features' accuracy and discrimination power, an elaborate feedback mechanism is devised. This mechanism is essential because of its complementary nature to the generalization process embedded in the generic recognition strategy.

WORK COMPLETED

Survey Phase:

The Key West Survey was executed on the nights of June 13th and 14th, 1999. The most useful imagery was collected on the second night as water conditions were slightly improved and the FILLS system operated non-stop between 9pm and 2:30am. Data was recorded continuously by CSS while 17 snapshots were recorded off Raytheon's waterfall display. The snapshots included the known mine and panels, other mine-like objects, and interesting examples of natural and manmade clutter.

Data Analysis Phase:

This phase of the project was delayed until late August, 1999 to accommodate the completion of the Raytheon funded development of the object identification algorithm. Under this contract, the algorithm code has been upgraded to incorporate a technique for complex object modeling that describes the topology of a complex object as a set of basic shapes whose contact with each other is defined in terms of location, penetration, and orientation. This technique was added to improve the classifier's functionality while trying to identify mines with large localized bio-growths that significantly perturbate the target shape. Such growths were observed on the Key West targets and present a very challenging identification problem.

The target cuer concept is currently being coded in Microsoft Visual C++ to run on a PC. Supporting code has been developed to convert various laser line scan system image formats into a binary matrix that can readily be input into the cuer and target identifier test programs.

RESULTS

Survey Phase:

Although the survey weather was excellent and the sea state mild, the imaging conditions within the water were rendered poor by what could best be described as an algal "snowstorm" in which large coagulated particle groups (on the order of one-half inch in diameter) streamed through the water column supported by strong currents. Water measurements have yet to be quantified but visibility was estimated at one-two meters. The FILLS sensor output indicated that fluorescence phenomena were practically negligible in the natural background and on the targets. Only low levels of fluorescence were visible in the panel image, which will be calibrated by CSS in controlled water at a later date.

Data Analysis Phase:

Mine imagery obtained revealed a high level of bio-fouling including but not limited to sponge growth and a fluffy algal coating. Very few man-made surfaces were evident in the diver inspections. The degree of fouling and resulting perturbations to object shape made it nearly impossible to distinguish the spherical mine from the box-shaped anchor in the top-down FILLS scenes. The prospects for positive object identification under these conditions are difficult to assess, especially without a larger sample set to understand the feature variability. At best, the identification process is reduced to detecting "blobs" within a defined size and shape range but with varied detailed and gross surface structure and as such discriminating between a fouled mine and a fouled concrete block or other mine-sized structure is not possible. Of course, if it were known that only highly fouled mines and/or their anchors were present in otherwise benign clutter, a special case strategy could be devised for searching this particular environment, but pursuing that application at this time should not be a priority.

IMPACT/APPLICATION

There is no indication yet that fluorescence cues can be exploited to aid automated or even manual detection or identification processes as applied to long term emplaced heavily bio-fouled mines. The test conditions may, however, have been inherently non-conducive to propagating fluorescence signals and may not be representative of any broader class of waters. Additionally, the bio-fouling was so extreme that its impact on target shape and signature may have prevented recognition under even the best of imaging conditions. From these two perspectives, our data collection was "worst-case" and does not support general conclusions about fluorescence utility.

As an immediate consequence, future analysis efforts on this project will concentrate primarily on data sets with less-fouled targets of interest from deployments in other environments that span a range of water conditions from clear to highly turbid.

TRANSITIONS

Successful and robust automated target cueing and identification techniques developed under this project have insertion potential into Navy programs such as AQS/20X and RMS.

RELATED PROJECTS

1 – Mike Strand (CSS) discusses the Key West survey in greater detail in "Survey of a WWII Derelict Minefield with a Fluorescence Laser Line Scan Sensor". This report also discusses the real-time implementation of CSS developed image enhancement and target cueing processes.

2 – Yensch and Phinney (Bigelow Labs) in "The Fouling of Mine Casing Surfaces by Fluorescent Organisms" are investigating shorter term and seasonal bio-fouling, and accompanying fluorescence signatures, on naval targets in Maine and Florida littoral regions.

REFERENCES

There are multiple references discussing the foundation upon which the computer vision concepts detailed herein are developed. A list of references is available upon request.